Bimodal spatial distribution of blue stragglers as a tracer of star cluster dynamical state

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Outline

- Part I:
  - bimodal spatial distribution of blue stragglers
- Part II:
  - BEANS software

The MOCCA code

- code for simulations of **real size** star clusters
- MOCCA == Monte Carlo method + Fewbody + SSE/BSE
  - spherical shells instead of stars; each shell is characterized by: mass (m), energy (E) and angular momentum (L).
  - relaxation process of a given object with all other objects in the system is approximated just by one interaction of two neighboring shells.
- it **agrees** with N-body codes very well (Giersz et al. 2013)
- it **scales** with the star cluster masses
- it is **fast**(!)
- it gives basically the same amount of information as N-body codes
- it allows detail comparison with observations of exotic star cluster objects e.g. **blue stragglers** (BSs)

What are blue stragglers?

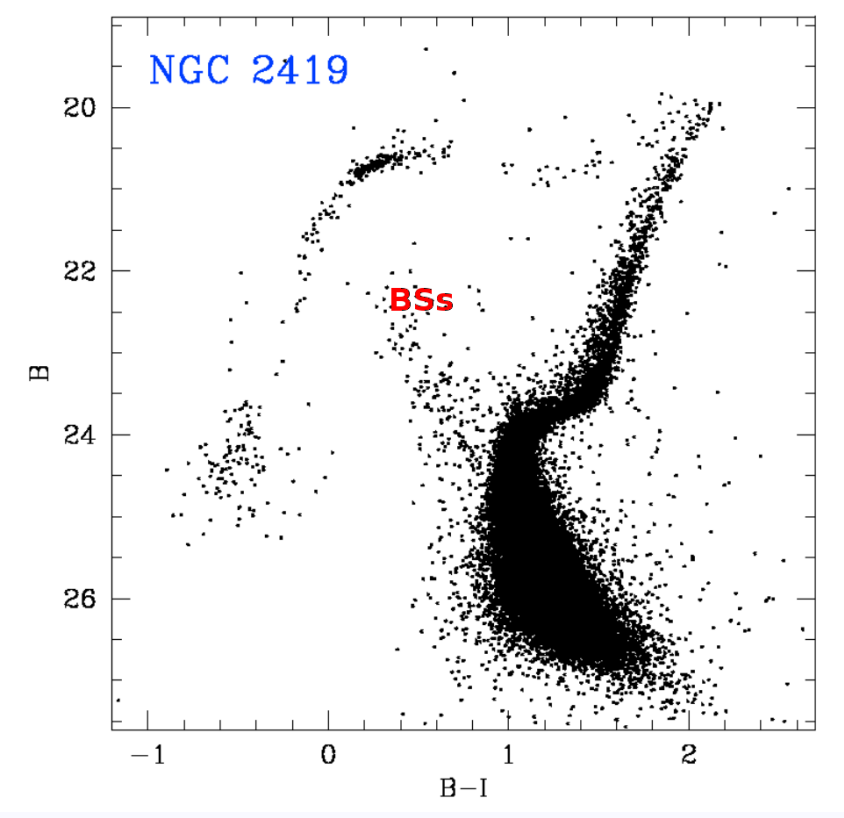

Figure: Example BSs in NGC2419

- BSs defined as stars which are brighter and bluer (hotter) than the main sequence turn-off point
- BSs lie along an extension of the main sequence in CMD
- it suggests that these objects got some additional mass
- BSs are present essentially in all star clusters

Two channels of formation: mass transfer and collisions

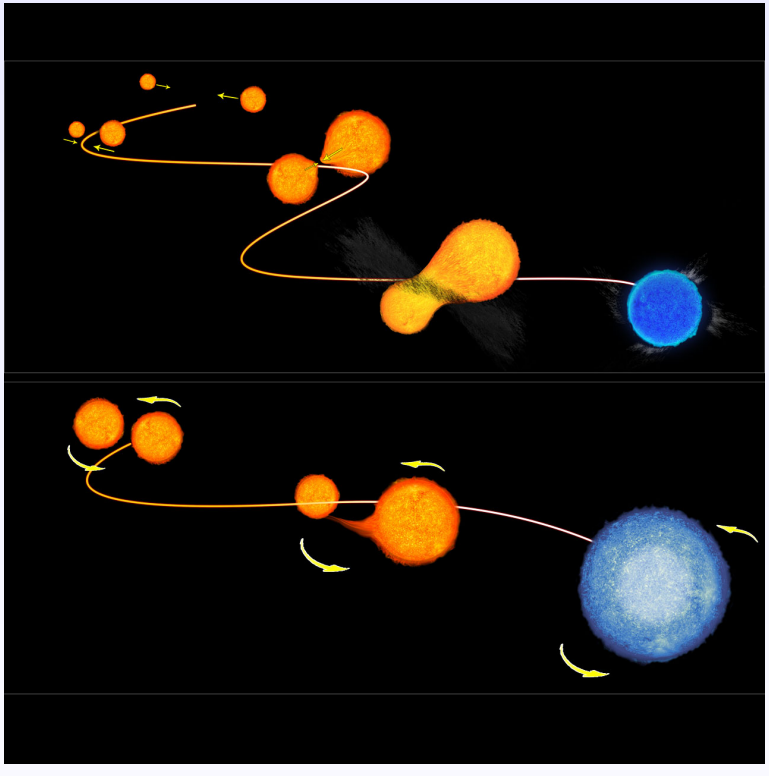

Figure: Mass transfer and collisional scenarios of BSs formation

- mass transfer (MT):
  - only for binaries (strong dependence on IMF)
  - BSs exceed only slightly turn-off (mostly)
  - MT leads to merger, which can create BSs too
- collisions (COLL):
  - dynamical interactions
  - important only for some star clusters

Bimodal spatial distribution

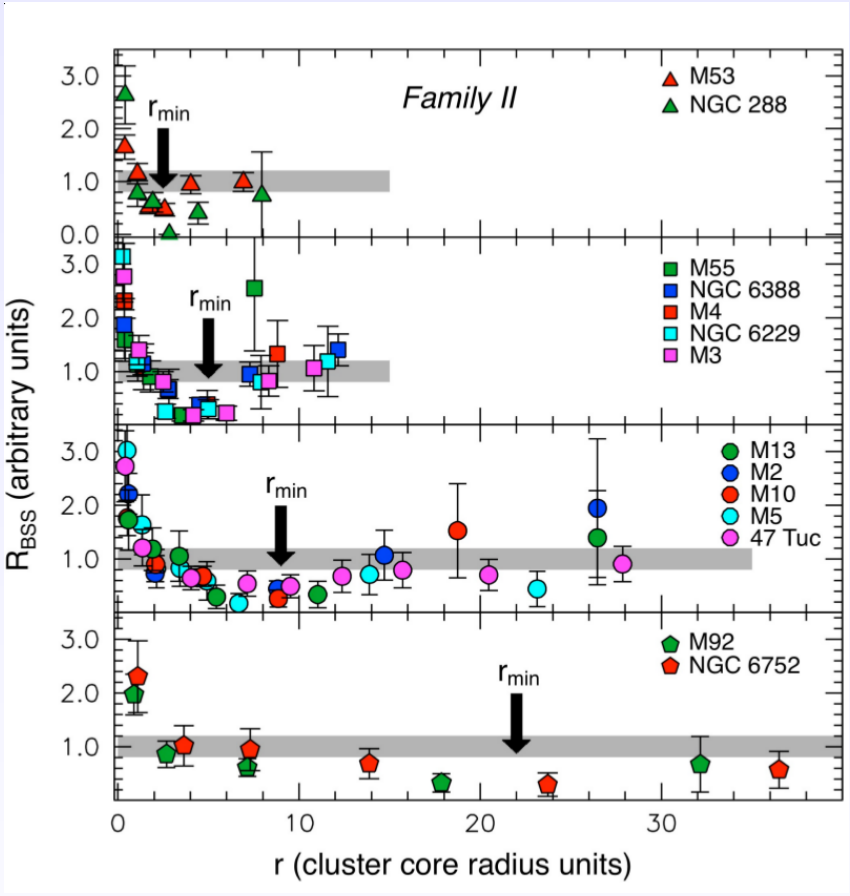

Figure: Bimodal spatial distributions for selected star clusters, Ferraro (2012)

- **maximum** at the center of the cluster, **clear-cut dip** in the intermediate region and **again rise** of BSS in the outer region of the cluster (but lower than the central value)
- bimodality is present for star clusters with various masses and concentrations

Bimodal spatial distribution - theories

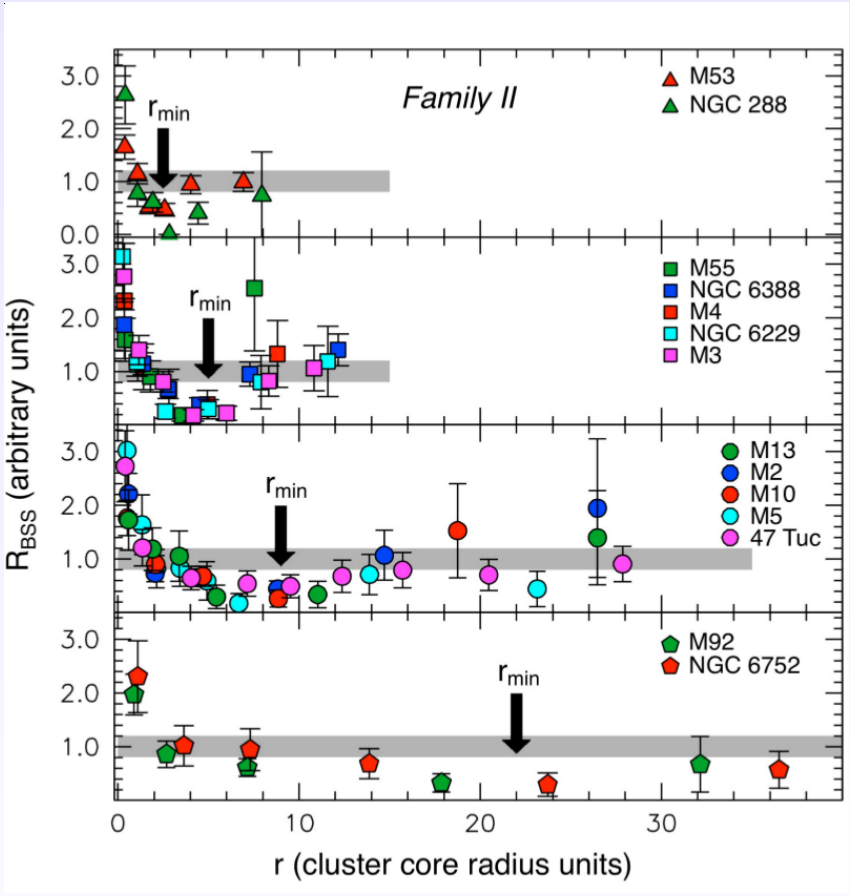

Figure: Bimodal spatial distribution for selected star clusters, Ferraro (2012)

- Sigurdsson (1997) suggested direct **collisions in the center and then ejection** to the outer part of the system as a result of a dynamical interaction
  - then **mass segregation** would move BSs to the center (except of BSs on large orbits)
- Ferraro (1997) suggested **different formation processes** in different parts of the cluster - mass transfer for the outer BSS and stellar collisions in the center

Bimodal spatial distribution - theories

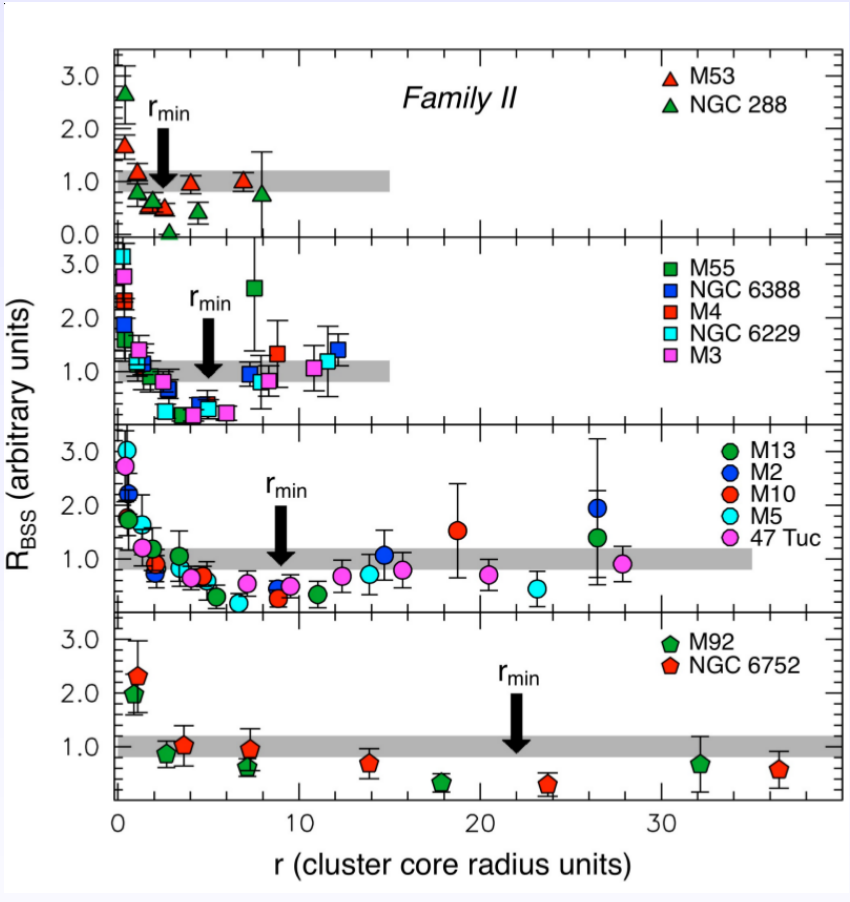

Figure: Bimodal spatial distribution for selected star clusters, Ferraro (2012)

- Mappeli (2004, 2006) showed using numerical simulations that **central number of BSs cannot be explained by collisional scenario**
  - observed radial distribution of BSs is primarily modeled by the **long-term effect of dynamical friction** acting on the cluster binary population (and its progeny) since the early stages of cluster evolution - leading theory today

Flat and monotonic spatial distributions

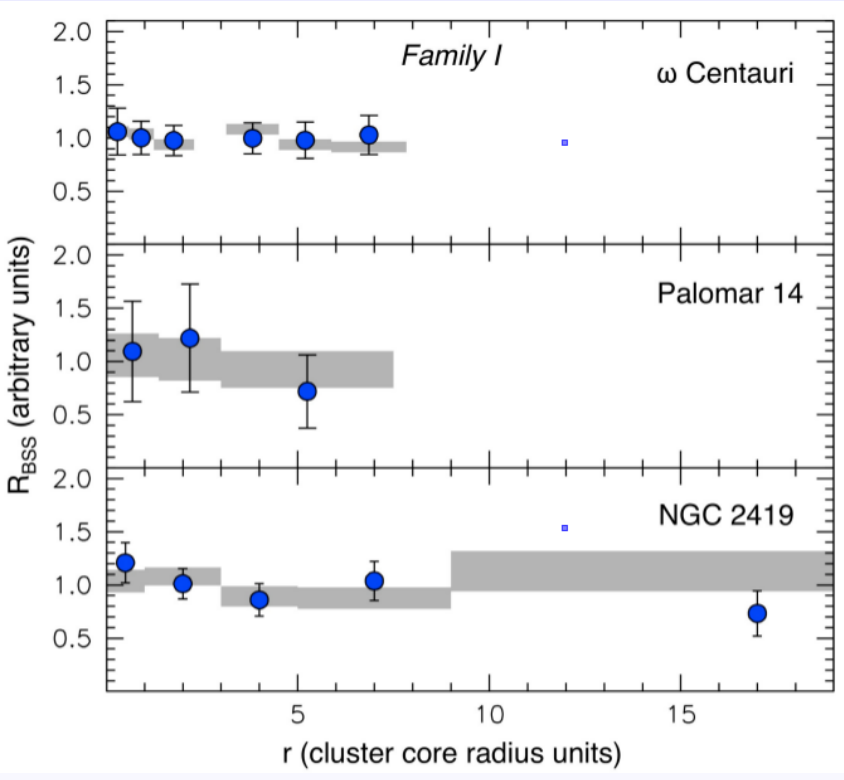

Figure: Examples of flat spatial distributions

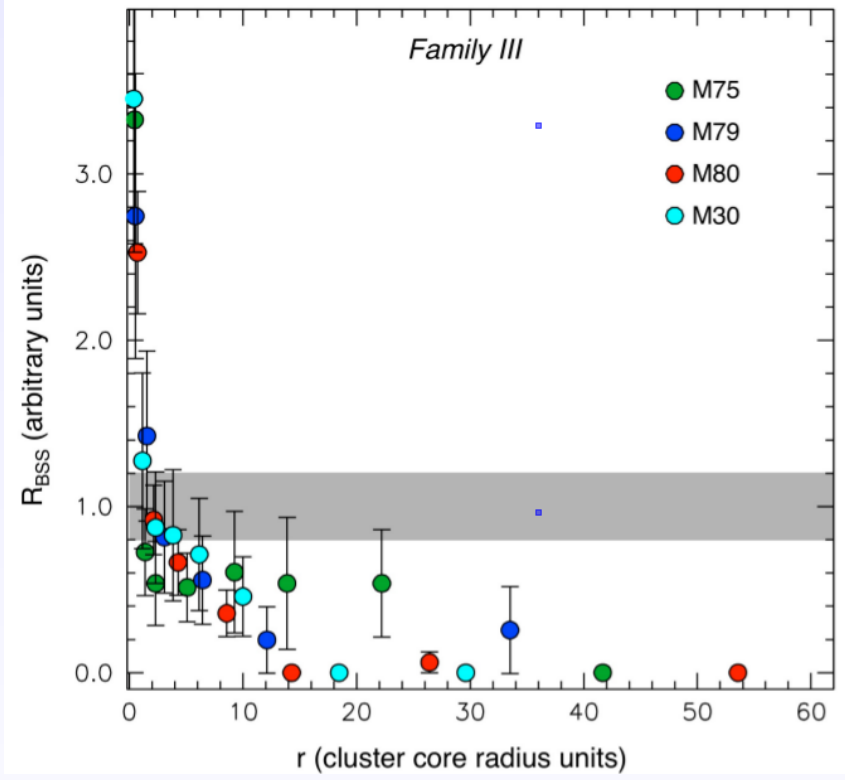

Figure: Examples of unimodal spatial distributions

Harris catalogue

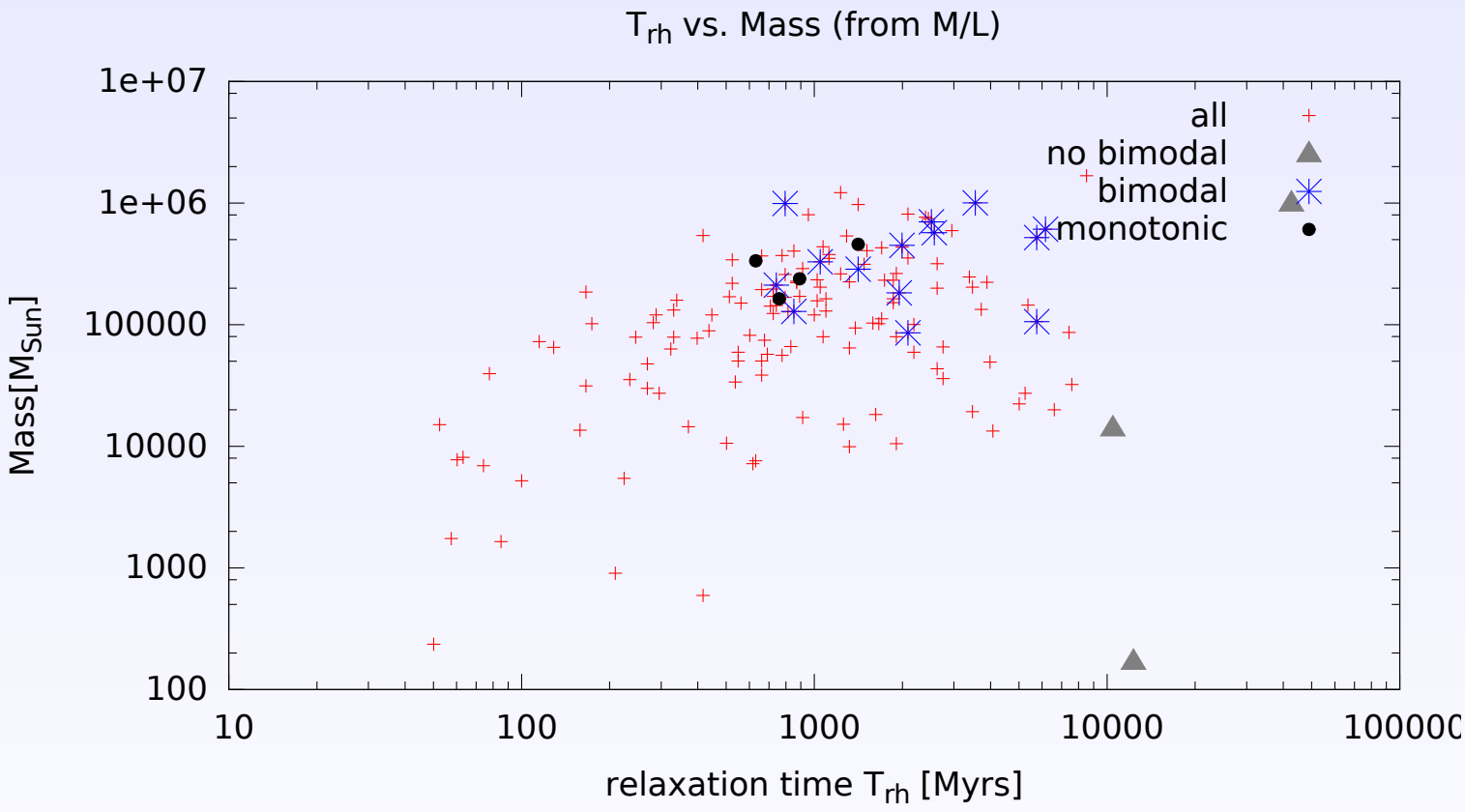

Figure: Bimodal spatial distributions for real star clusters

BIMODAL spatial distribution

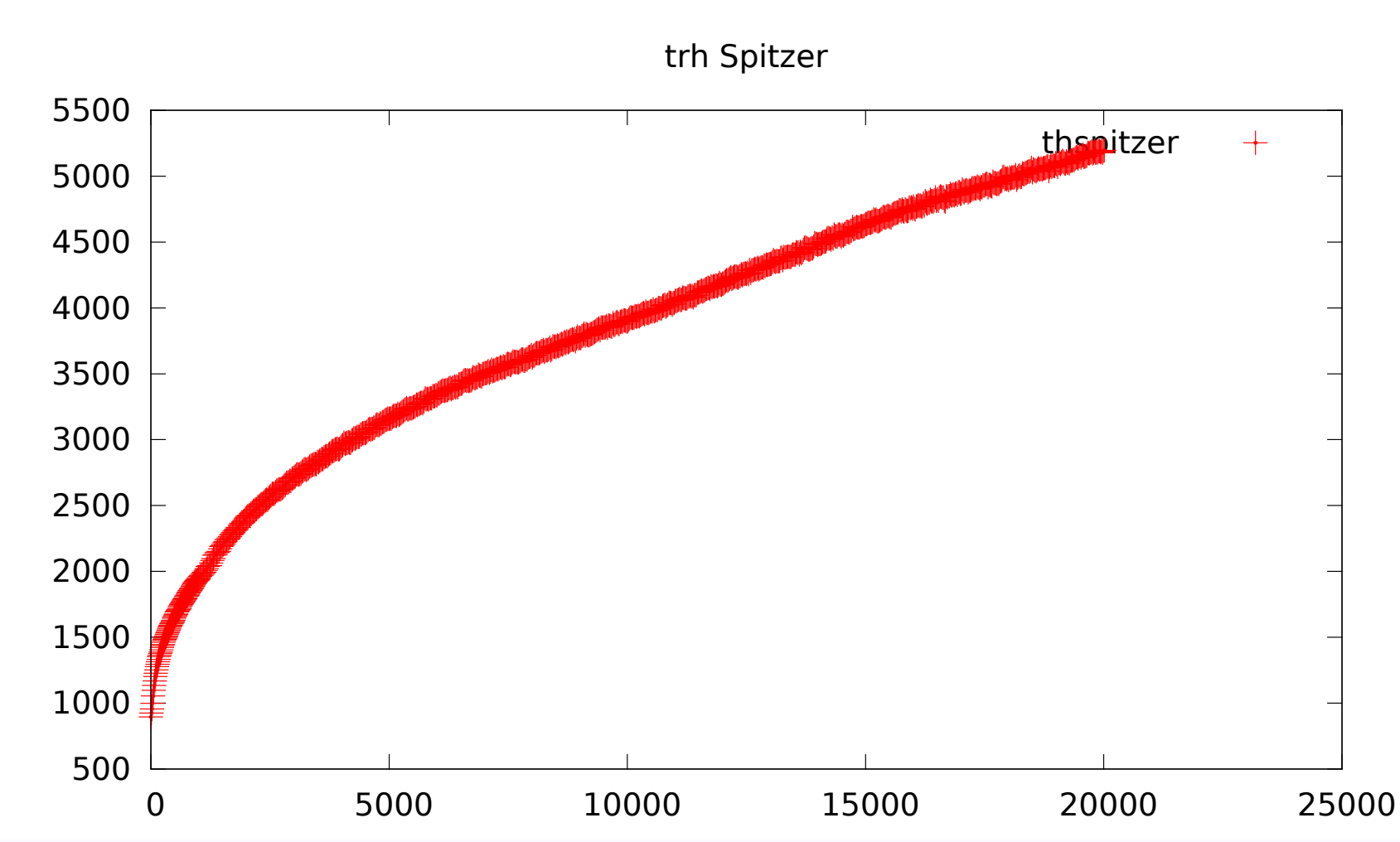

Figure: Half-mass relaxation time for 600k, rplum=40

BIMODAL spatial distribution

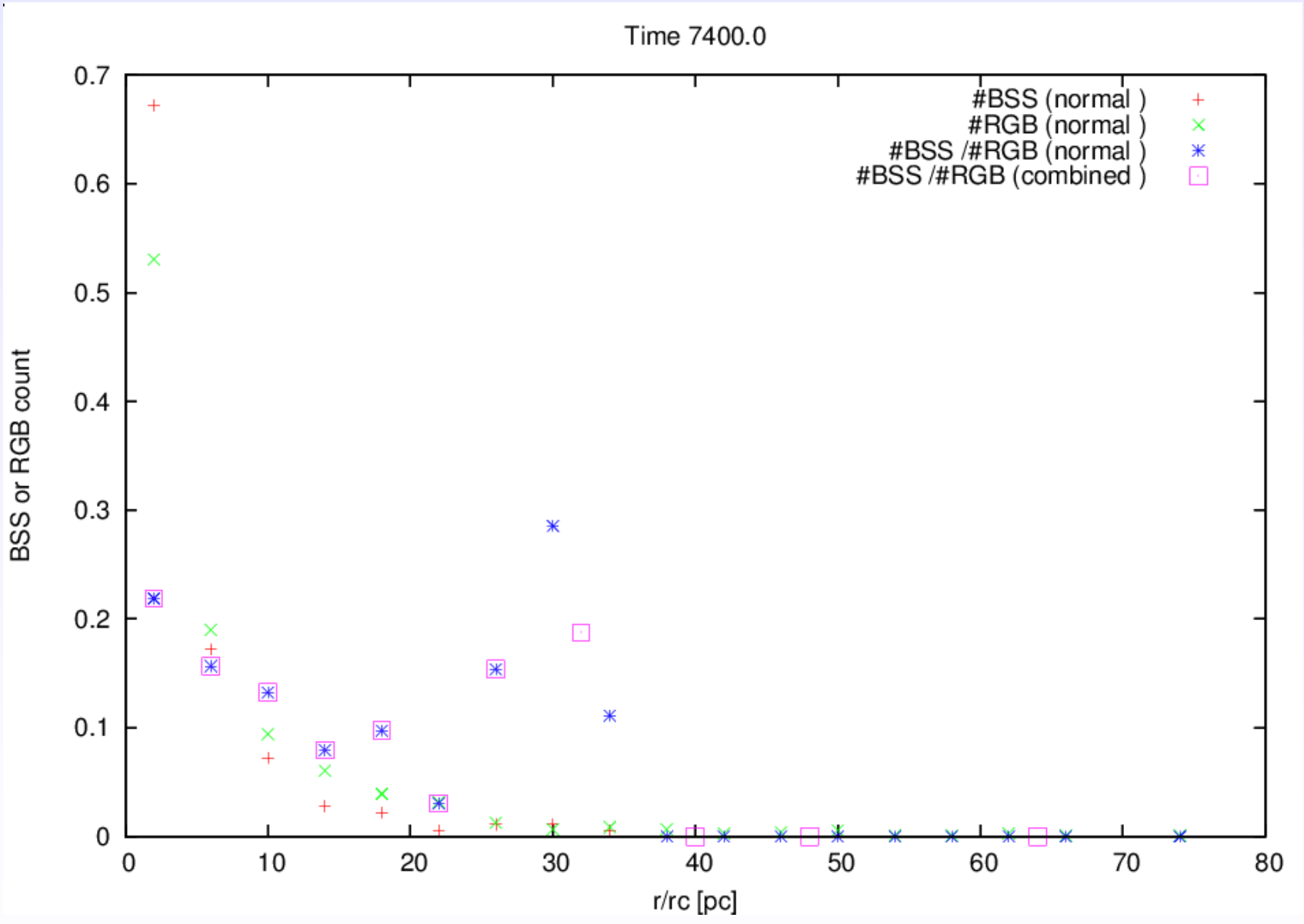

Figure: bimodal spatial distribution for 600k, rplum=40, 7Gyrs

UNIMODAL spatial distribution

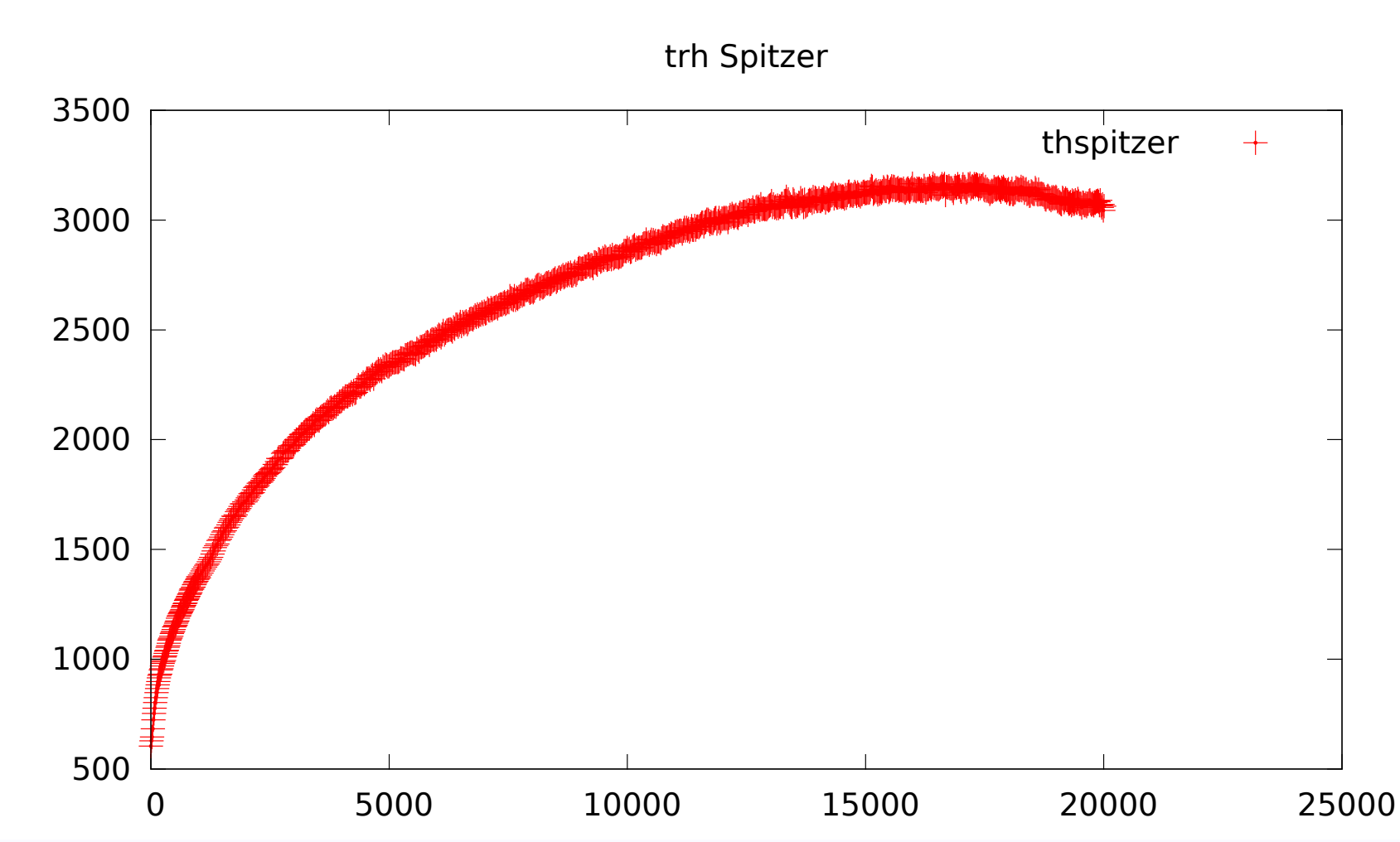

Figure: Half-mass relaxation time for 300k, rplum=30

UNIMODAL spatial distribution

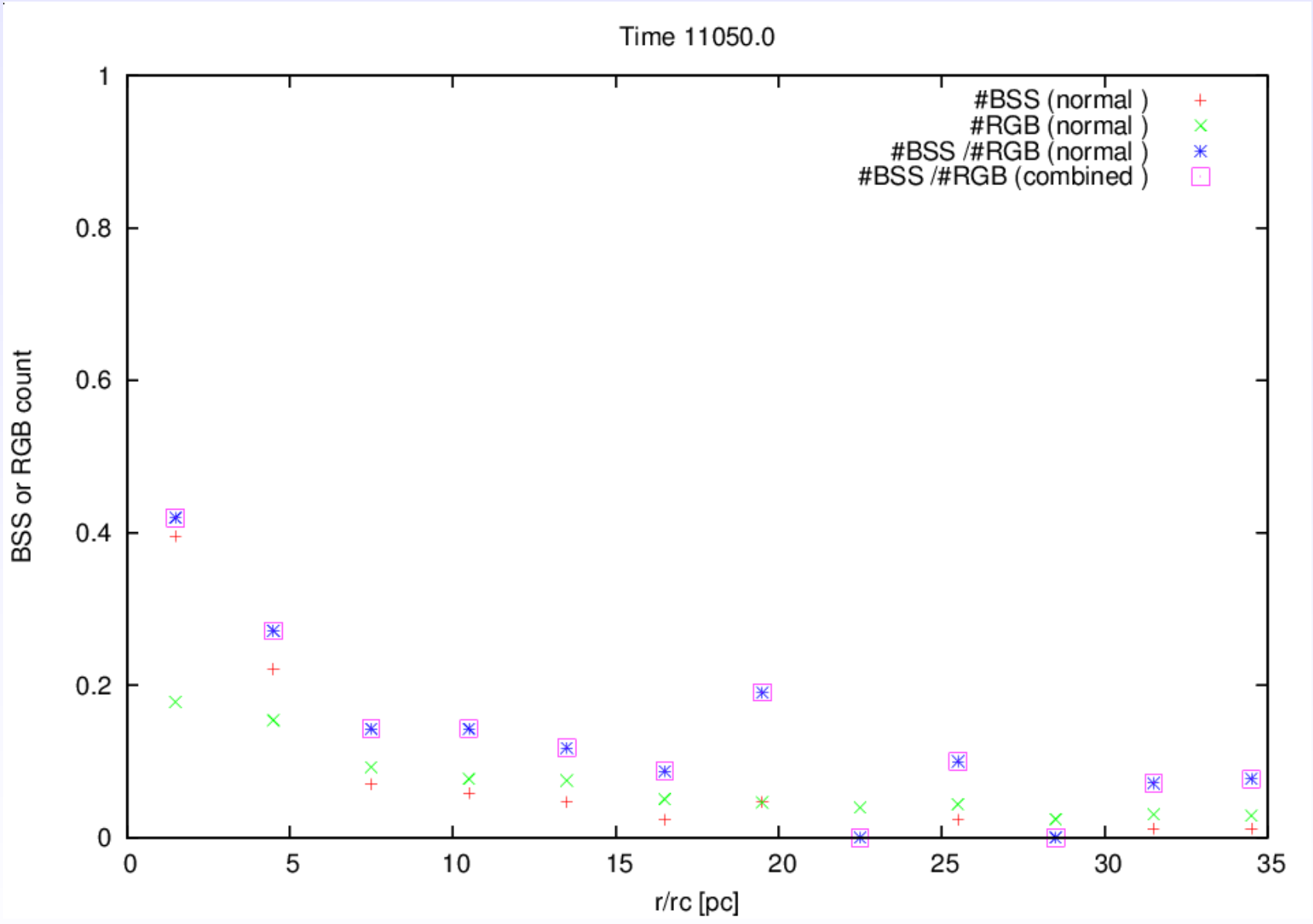

Figure: unimodal spatial distribution for 300k, rplum=30, 11Gyrs

FLAT spatial distribution

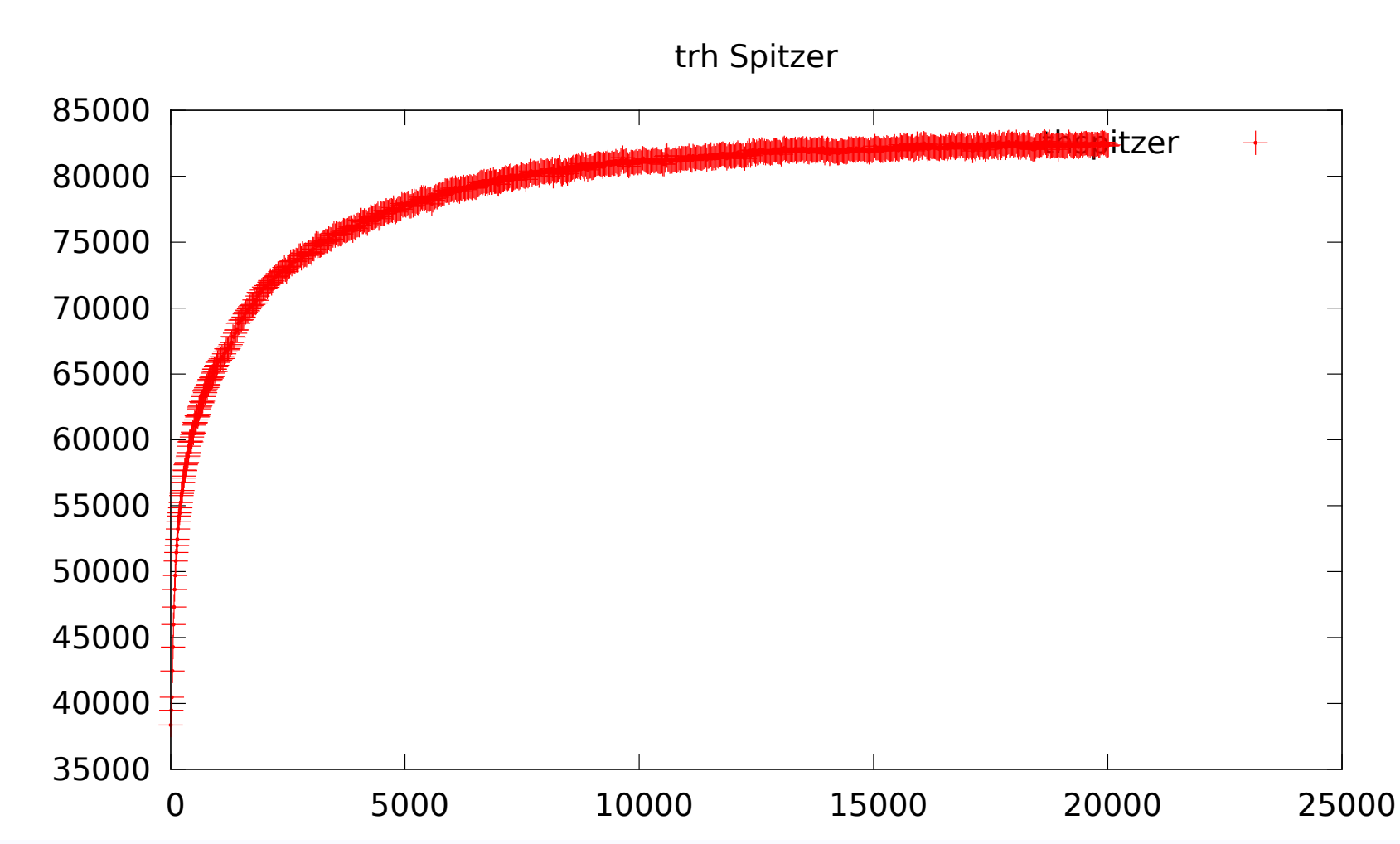

Figure: Half-mass relaxation time for 600k, rbar=300

FLAT spatial distribution

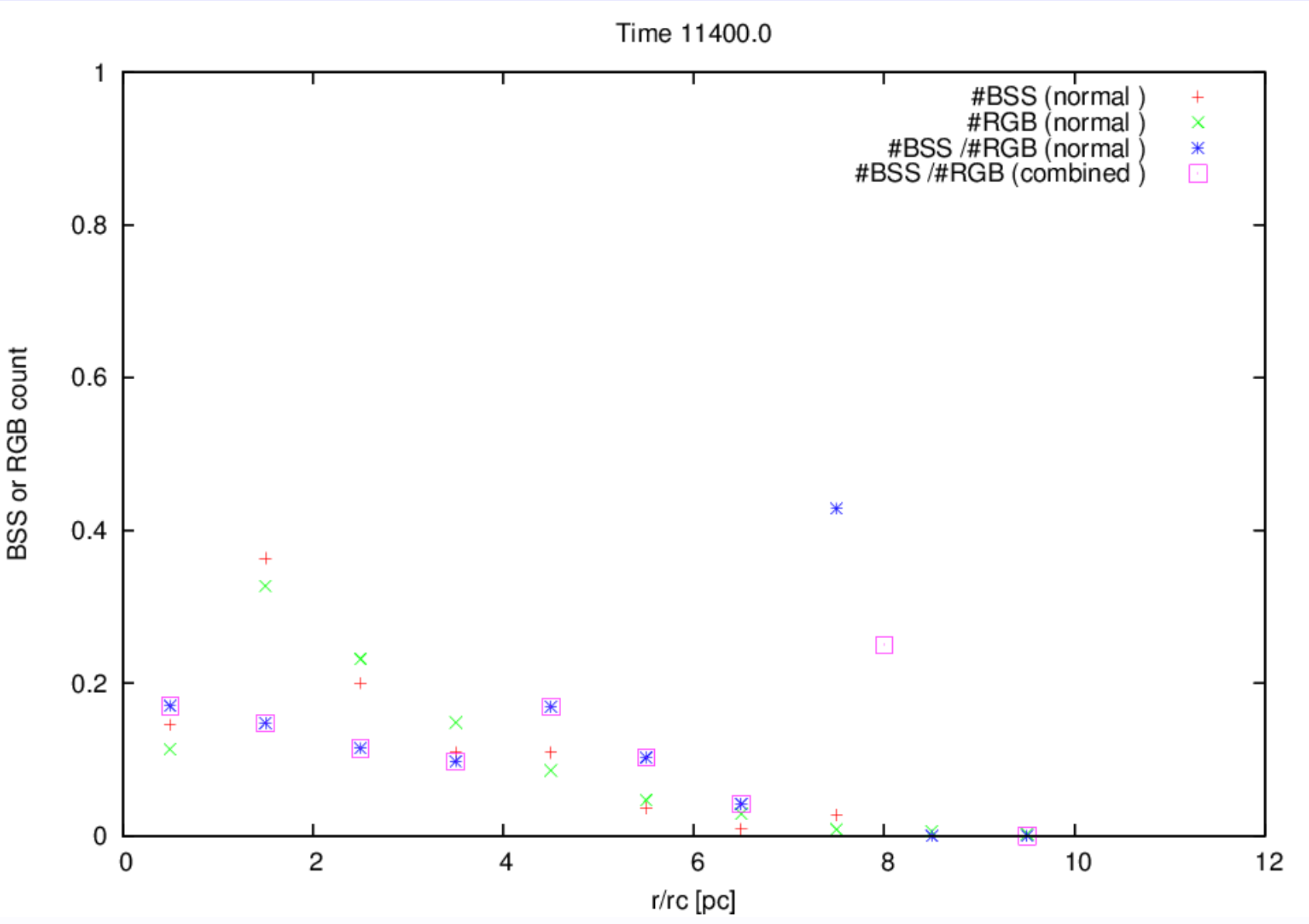

Figure: Flat distribution for 600k, rbar=300, 11 Gyrs

Searching for bimodality - challenges

- it's **tricky to reproduce** masses and t_{rh} as for real star clusters
- there is basically no problem with showing **qualitatively** models with flat, unimodal and bimodal spatial distributions
- ... but the real challenge is to find **quantitative** prescriptions for bimodality
  - mysterious interplay between half-mass relaxation times, concentrations and lifetimes(?) of blue stragglers
  - internal BSs positions 'noise'
  - vanishing bimodality signal (MOCCA's fault? or feature?)

Summary

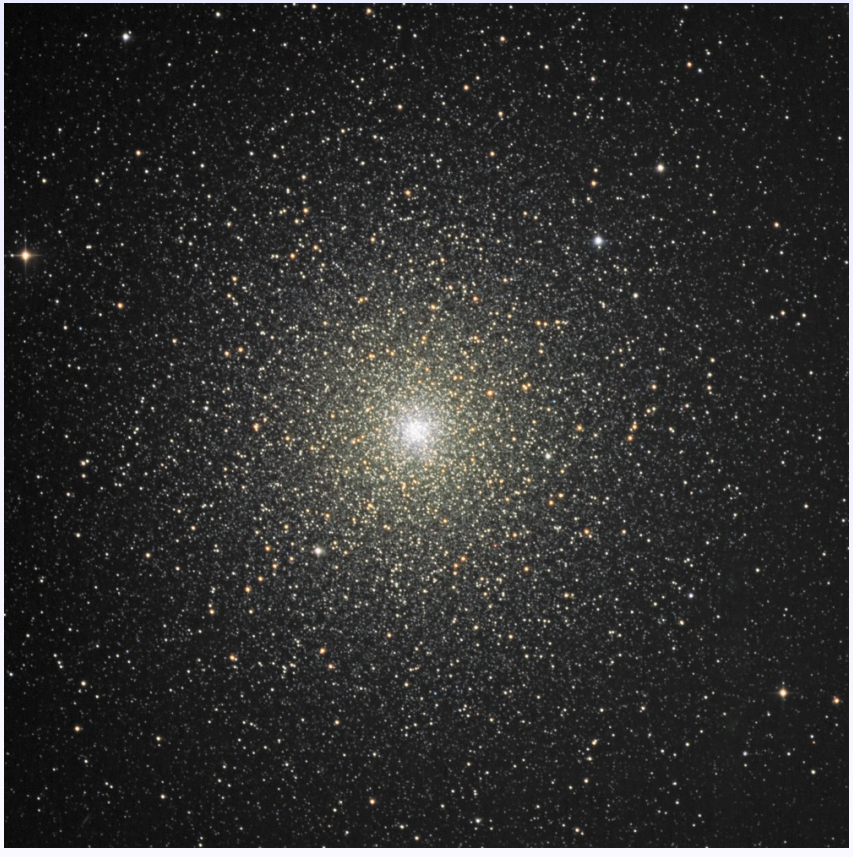

Figure: 47 Tuc

- **bimodal spatial distribution** seem to form for evolving clusters:
  - age of the star cluster has to be larger then t_{rh}
  - signal of bimodal spatial distribution vanishes for star clusters where crossing times are comparable with t_{rh}
- **flat** bimodal spatial distributions seem to be present for dynamically young star clusters
- **unimodal** spatial distribution seem to be present for relaxed star clusters

The BEANS software

- it's a **good time to think about data/results** analysis/comparison
  - many codes are Open Source, what about the results?
- **one place** for different data (MOCCA, N-body, observational data)
- easy and uniform access to **query, aggregate and visualize** the data
  - human-readable, very powerful scripts
  - one database, one web-based interface (works everywhere)
- **fast for big jobs** (parallel data processing)
  - distributed out of the box
  - typical use cases: many different simulations, huge datasets
- **powerful plots** (D3 library, `http://d3js.org`)
- ...

The BEANS software

Figure: Selected software used in BEANS

- How?
  - Apache Cassandra: high available, fault-tolerant, decentralized, durable, incredibly fast database
  - Apache Pig: high-level language to work with MapReduce paradigm
  - D3: powerful, non-standard visualization library (`http://d3js.org`)
- $\rightarrow$ two examples